

# Prototyping global Earth System Models at high resolution: Representation of Eastern Boundary Currents

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With special appreciation of the climate model development in:

Delworth, T. L., A. Rosati, W. G. Anderson, A. Adcroft, V. Balaji, R. Benson, K. W. Dixon, S. M. Griffies, H.-C. Lee, R. C. Pacanowski, G. A. Vecchi, A. T. Wittenberg, F. Zhang, and R. Zhang, 2012:  
Simulated climate and climate change in the GFDL CM2.5 high  
resolution coupled climate model, *J. Clim.*, **25**, DOI:10.1175/JCLI-  
D-11-00316.1

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# Outline

- Eastern Boundary Currents (EBCs) under Climate Change
- The need for a hierarchy of model approaches
- Prototype ESM2.6 fidelity



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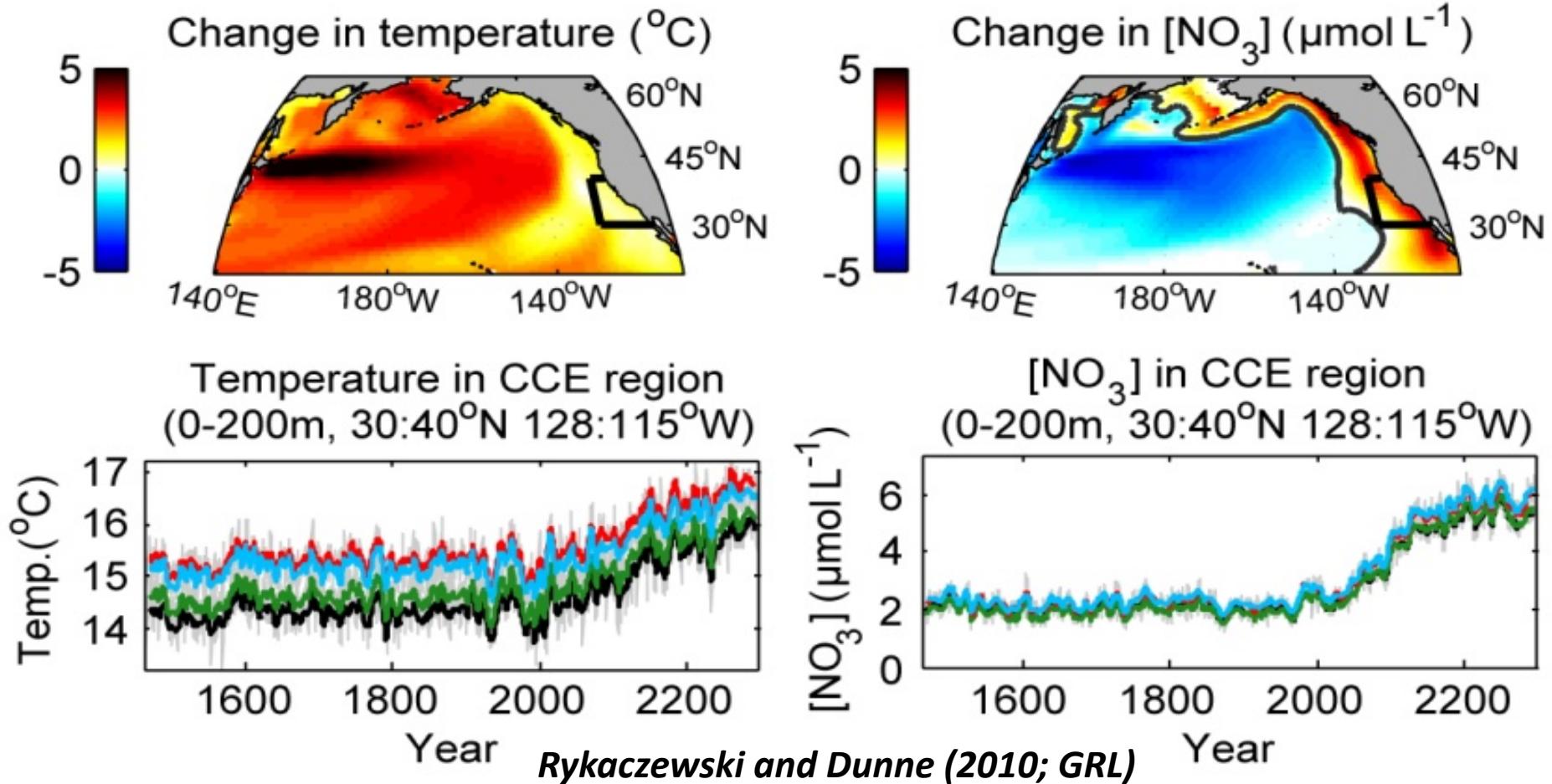
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# EBC Productivity and Water Quality

- Some of the world's most productive fisheries
- Low oxygen (hypoxia)
  - Observations of fish and crab kills
- Low pH (natural acidification)
  - Observations of reduced oyster productivity
- Anthropogenic acidification and climate concerns
  - Anthropogenic CO<sub>2</sub> (acidification) increases
  - Long term observed increase in hypoxia

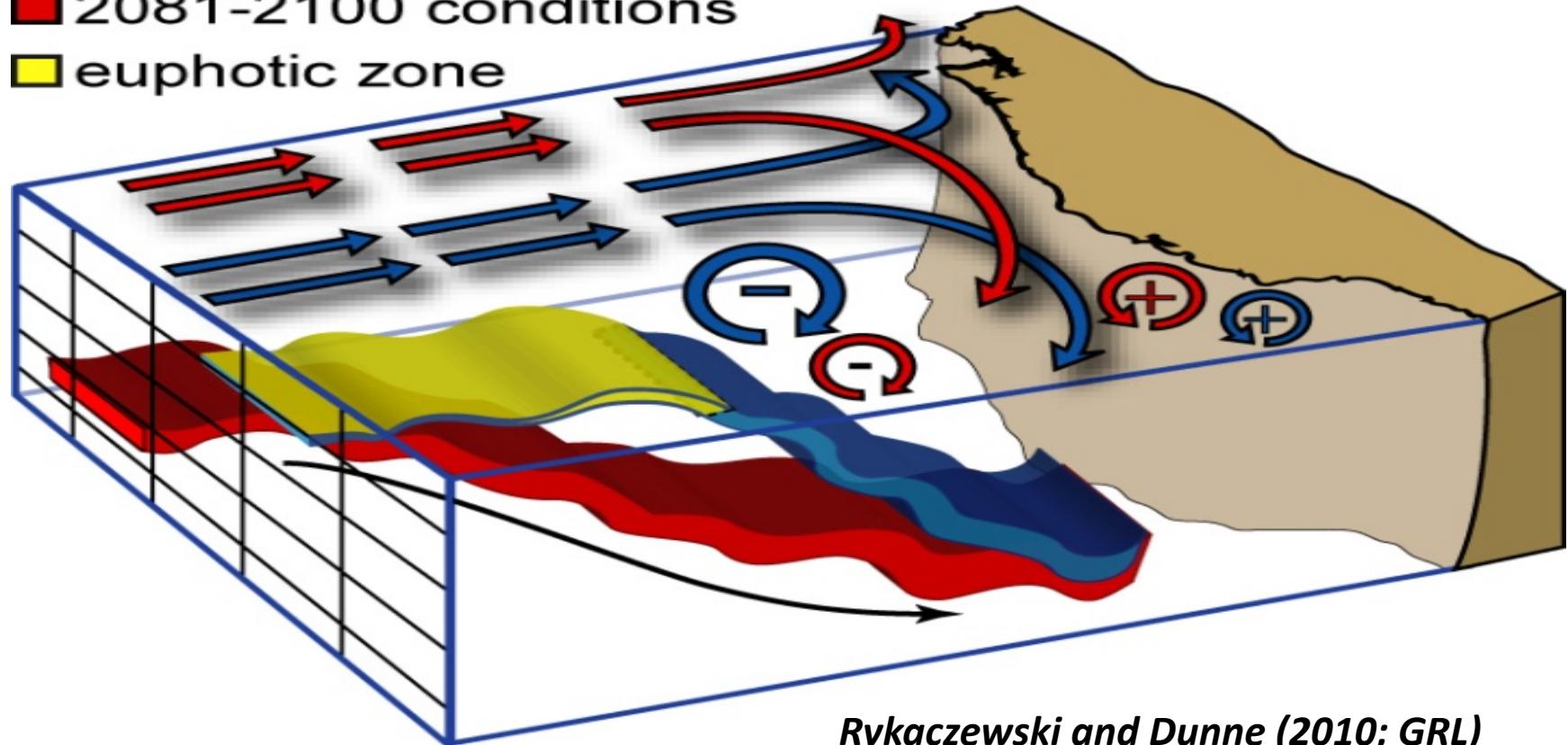
# Relating large scale climate changes to EBCs



- Early GFDL Earth System Model (ESM2.1) with historical and SRES A2 forcing
- Decreased  $\text{NO}_3$  in gyre, but increased  $\text{NO}_3$  in the California Current
- While T and  $\text{NO}_3$  are negatively correlated seasonally and inter-annually, they are positively correlated under climate change

# Relating large-scale changes to the California Current

■ pre-industrial conditions  
■ 2081-2100 conditions  
■ euphotic zone



*Rykaczewski and Dunne (2010; GRL)*

- Dominance of remote forcing on local California Current changes
- Interplay of changes in atmospheric winds and heat fluxes, stratification, ventilation, and watermass pathways modulating biogeochemical response

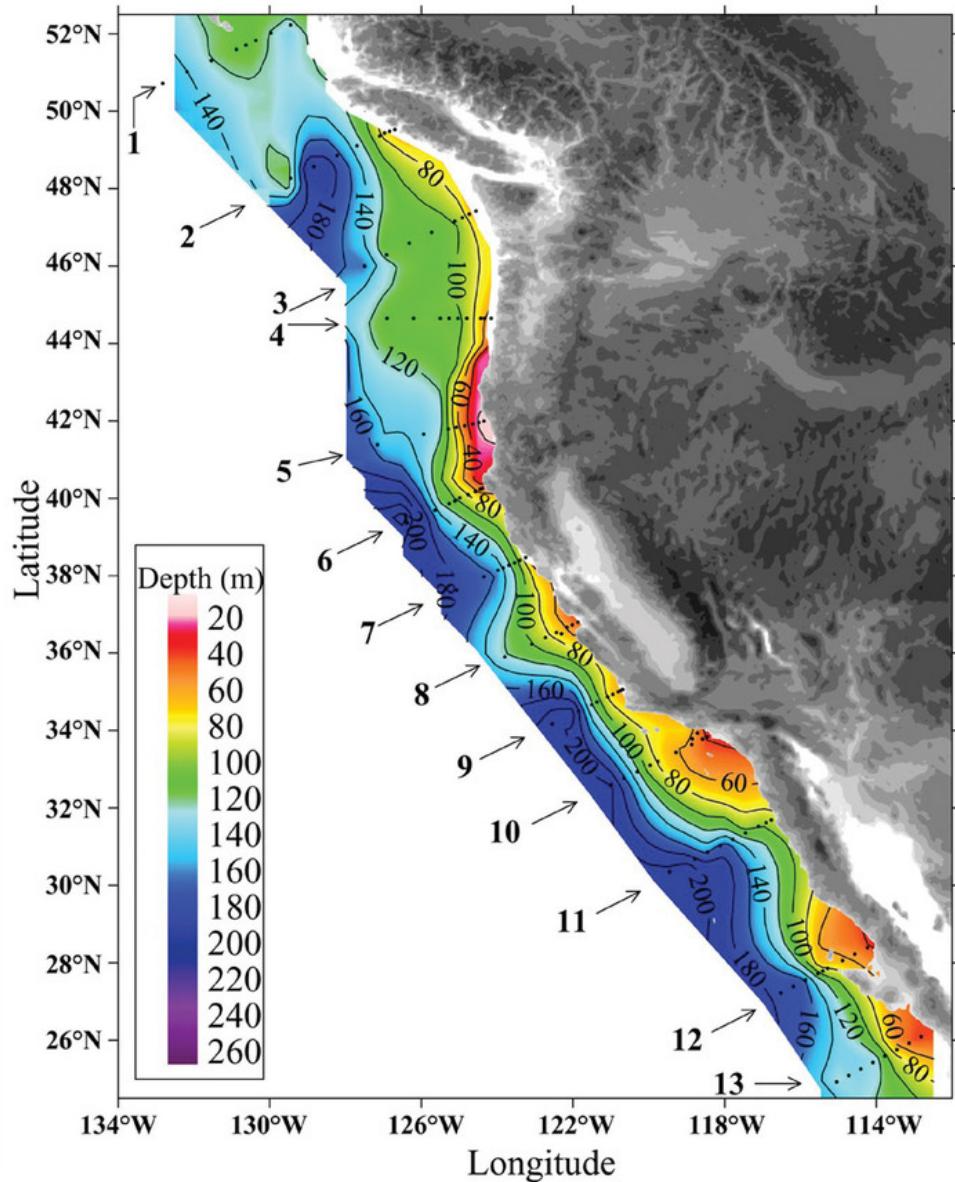
... But are we using the right tool for the job?

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# EBC Acidification Observations

## Depth of Aragonite saturation



Intensified nutrient remineralization and associated natural acidification are coherent features all along the California Current EBC, but restricted to 10-100 km from the coast.

Feely et al. (2008; Science)

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# EBC Modes of Variability

- Seasonal cycle driving pressure gradients and winds
- Remote inter-annual forcings (ENSO, PDO, NPGO)
- Weather (days to weeks)
- Mesoscale eddies (100-150 days, 30-50km)
- Squirts, fronts and jets (e.g. topographic forcing)
- Diurnal sea breeze (km scale)

... 1°models only capture 2 or 3 of these mechanisms

# Statement of the problem

- Current  $1^\circ$  ESMs do not represent:
  - The position and variability of major current structures
  - The scales of either coastal or curl-driven upwelling
  - Topographic and land-sea atmospheric interactions
  - Mechanistic ecological interactions
- At least  $1/10^\circ$  is necessary to simulate these scales
- Adding tracers is also computationally expensive

# A hierarchy of Biogeochemical Tools

- CMIP5-generation GFDL Earth System Models:
  - Tracers of Ocean Phytoplankton with Allometric Zooplankton (**TOPAZ**) – 30 prognostic tracers with extensive BGC but parameterized ecosystem (Dunne et al., 2005; 2007; 2010; 2013)
- Ecological Mechanisms for Living Marine Resource Applications
  - Carbon, Ocean Biogeochemistry and Lower Trophics (**COBALT**) – 33 prognostic tracers based on **TOPAZ** with extensive ecosystem but fixed N:P (Stock and Dunne 2010; Stock et al, 2013)
- But each tracer costs 10-25% to computational burden...
  - Biogeochemistry with Light, Nutrients and Gas (**BLING**) – Reduced version of **TOPAZ** with 6 prognostic tracers (Galbraith et al, 2012)
  - Mini-BLING – Reduced version of **BLING** with only 3 prognostic tracers: Dissolved Inorganic Carbon, Phosphate, and Oxygen

# Prototype COBALT-ESM2.6 29-year test

- 1/10° Ocean (MOM5)
- 1/2° Atmosphere (AM2-Cube sphere)
- Ocean biogeochemistry and ecosystems (COBALT)
- Land ecosystems (LM3)
- 15744 cores
- $\sim 5$  model months day $^{-1}$
- $\sim 100$  GB month $^{-1}$

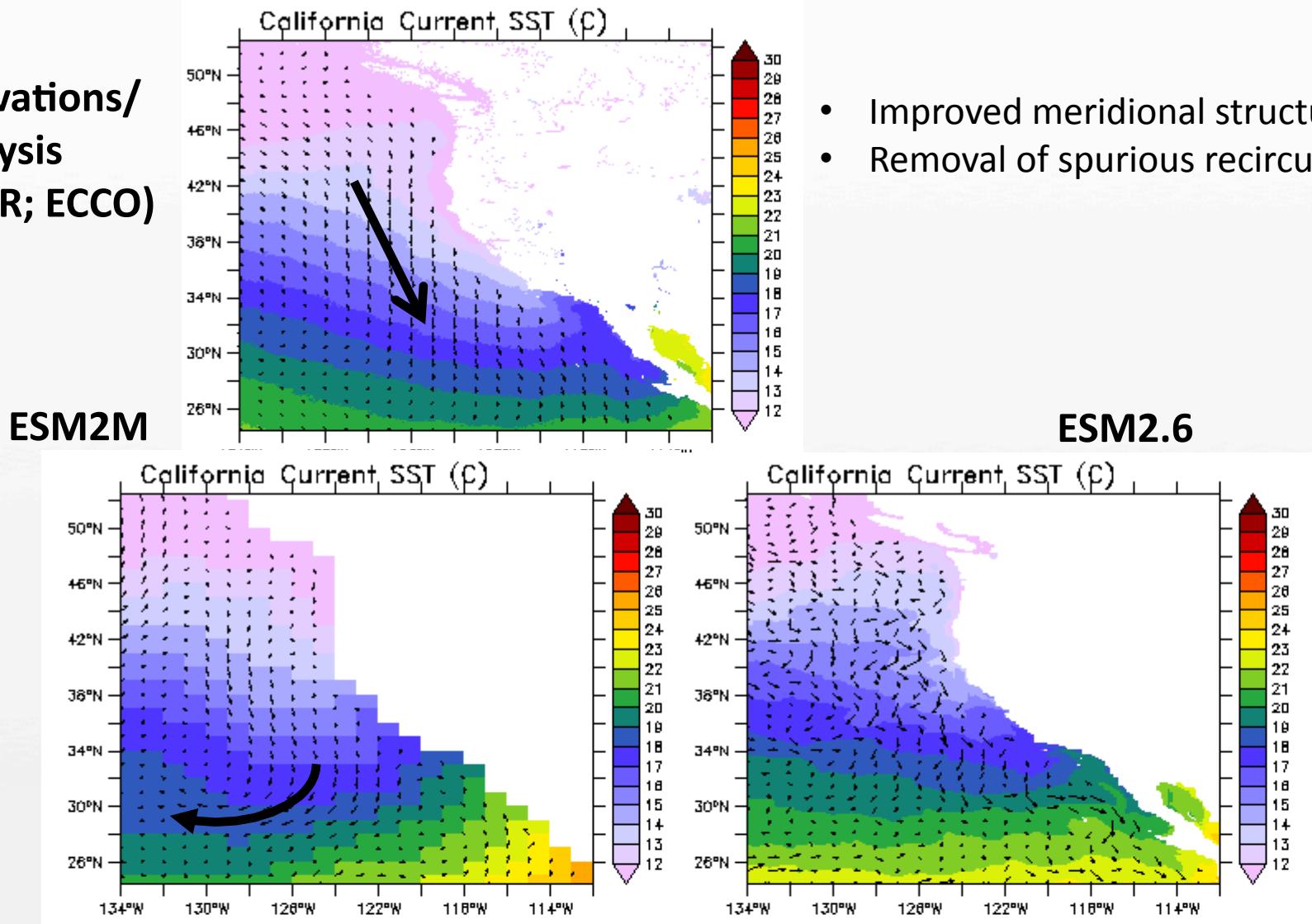


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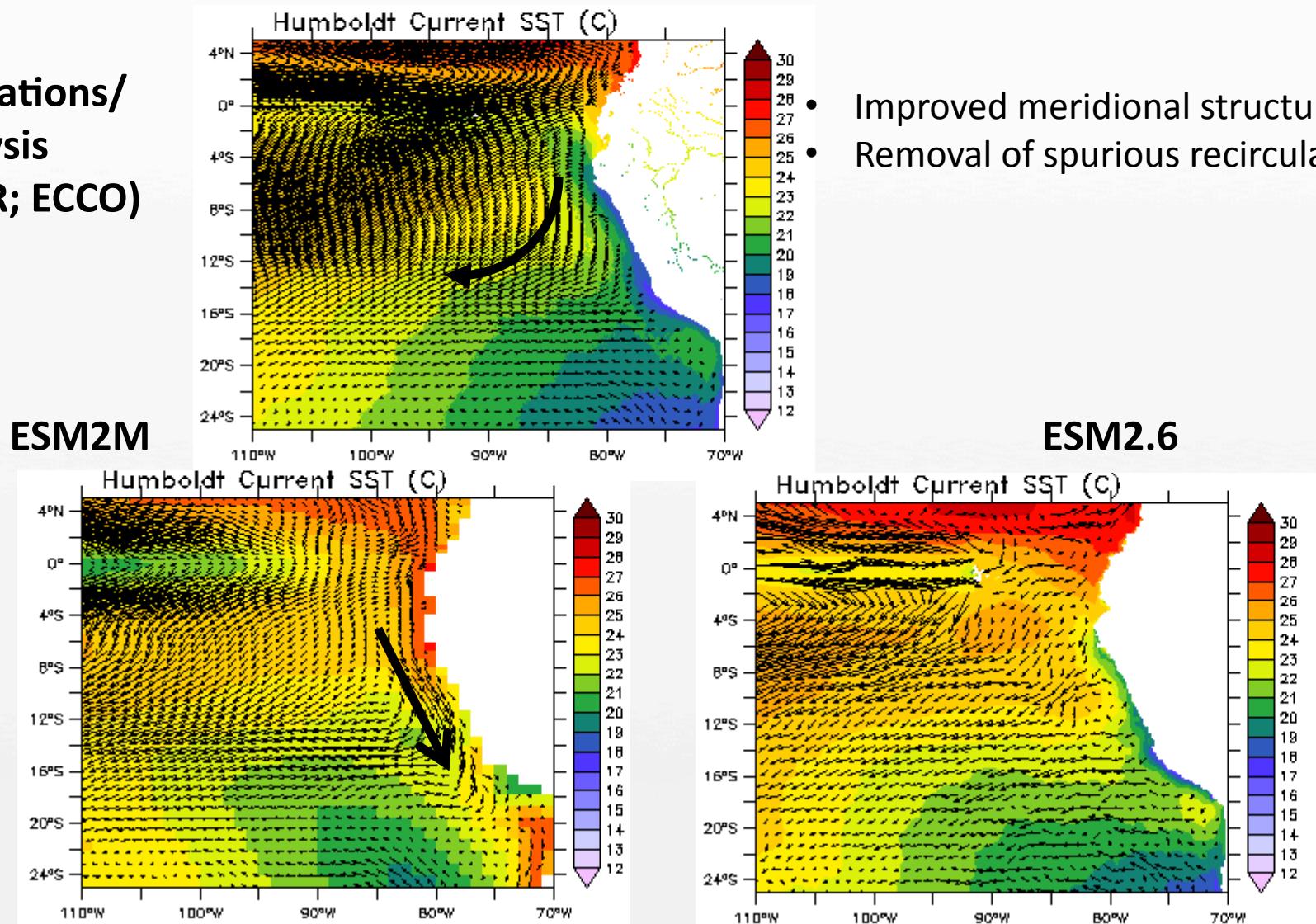
# California SST and 0-50m Currents

Observations/  
reanalysis  
(AVHRR; ECCO)



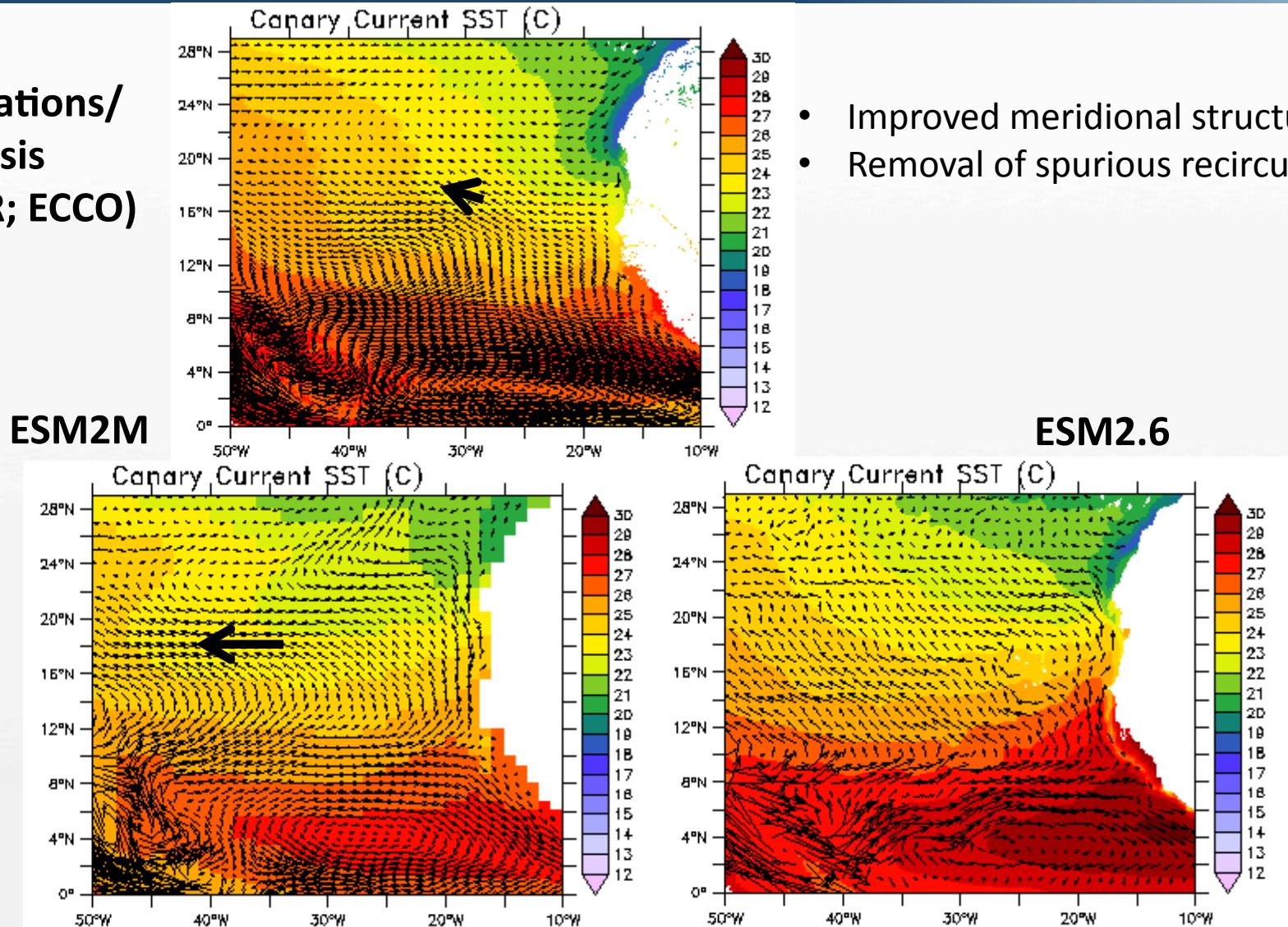
# Humboldt SST and 0-50m Currents

Observations/  
reanalysis  
(AVHRR; ECCO)



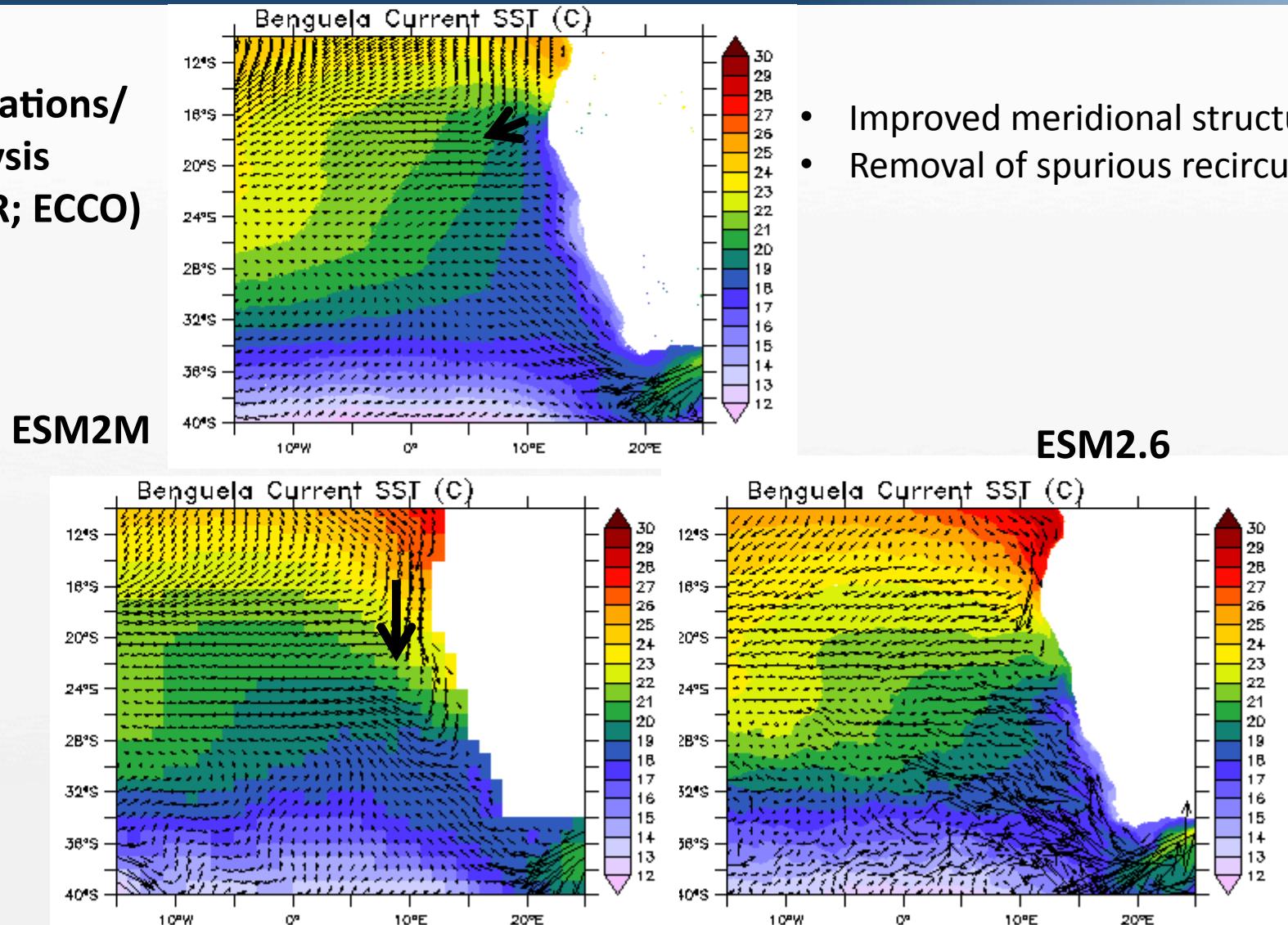
# Canary SST and 0-50m Currents

Observations/  
reanalysis  
(AVHRR; ECCO)

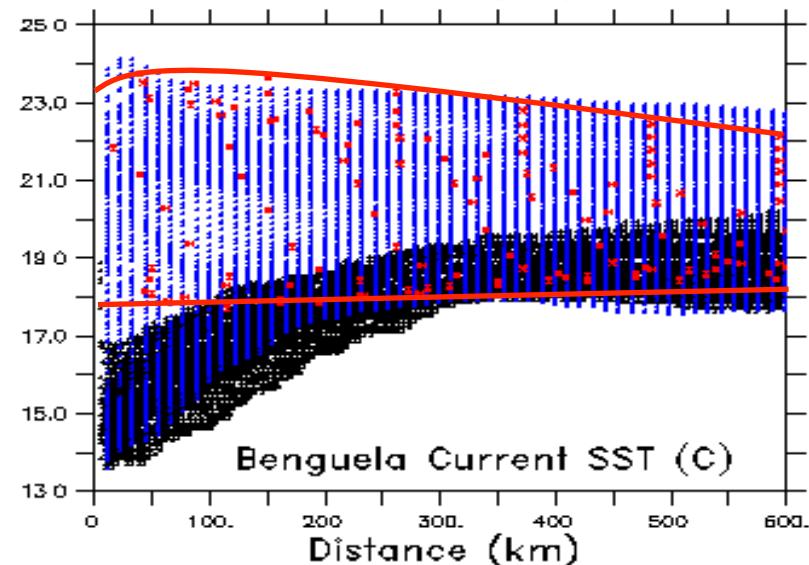
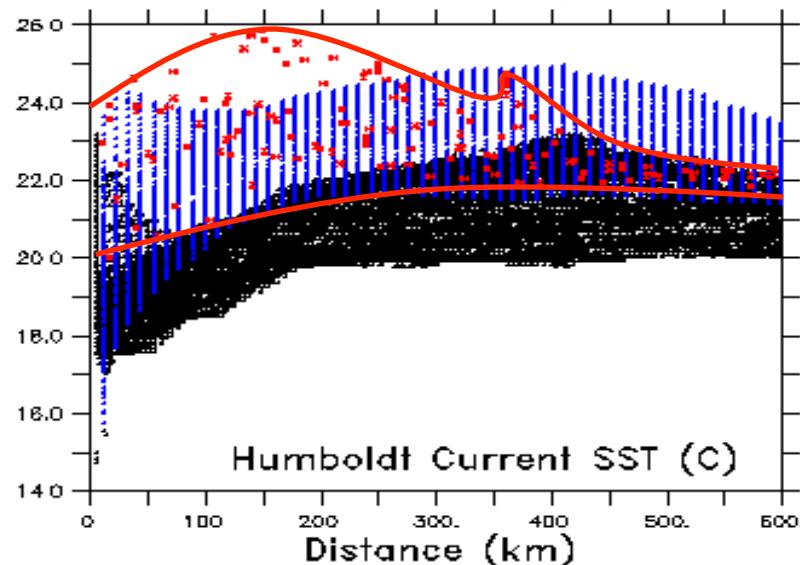
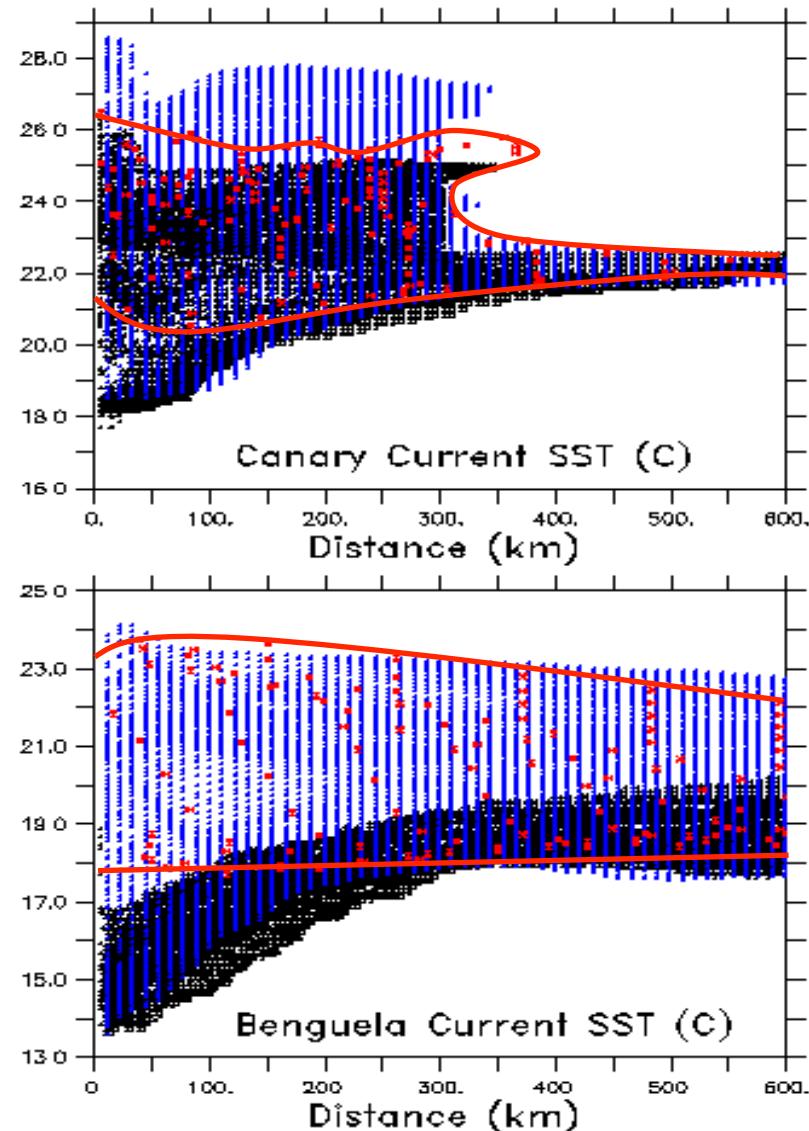
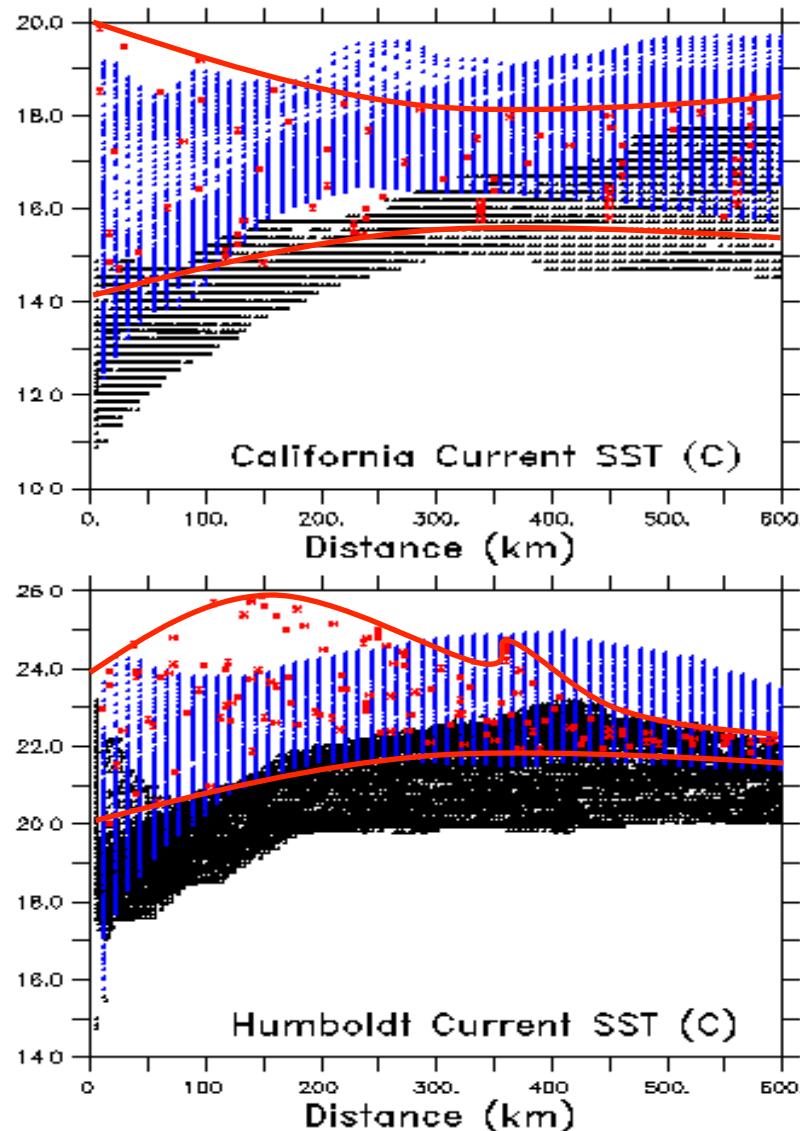


# Benguela SST and 0-50m Currents

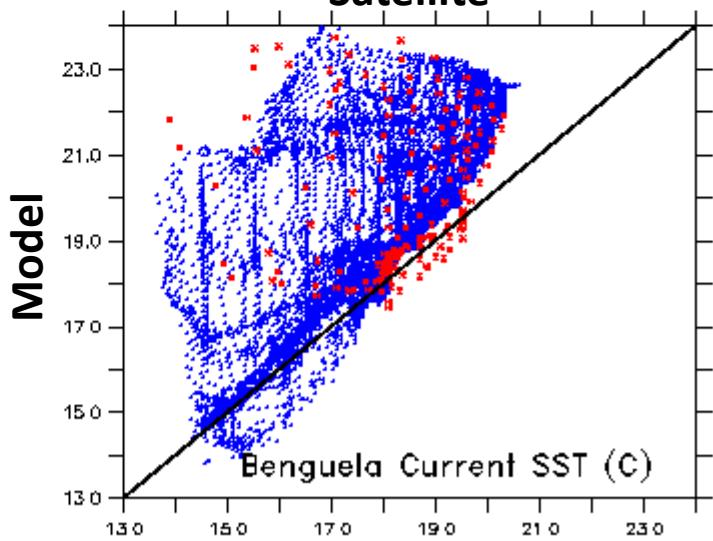
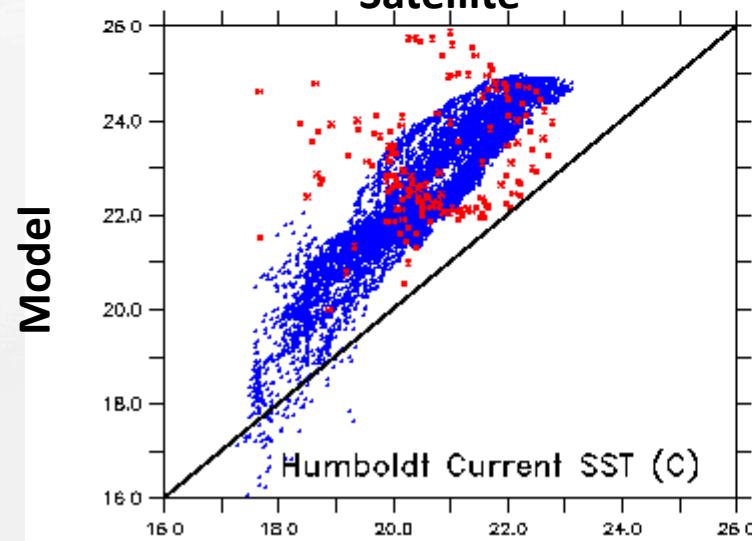
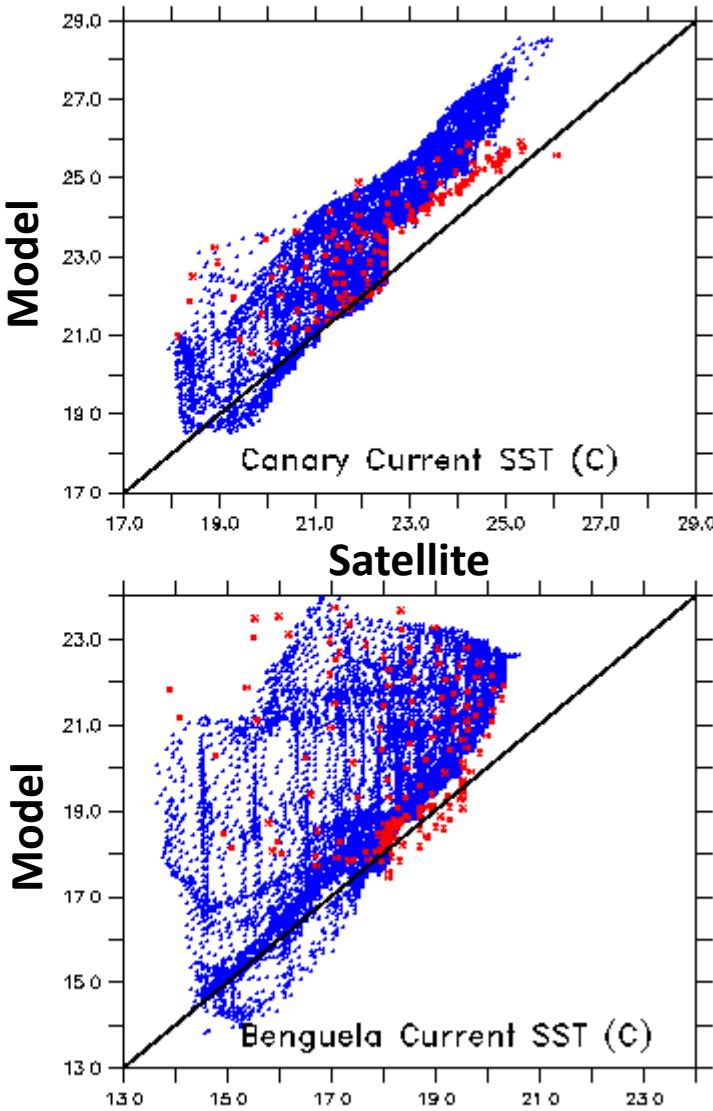
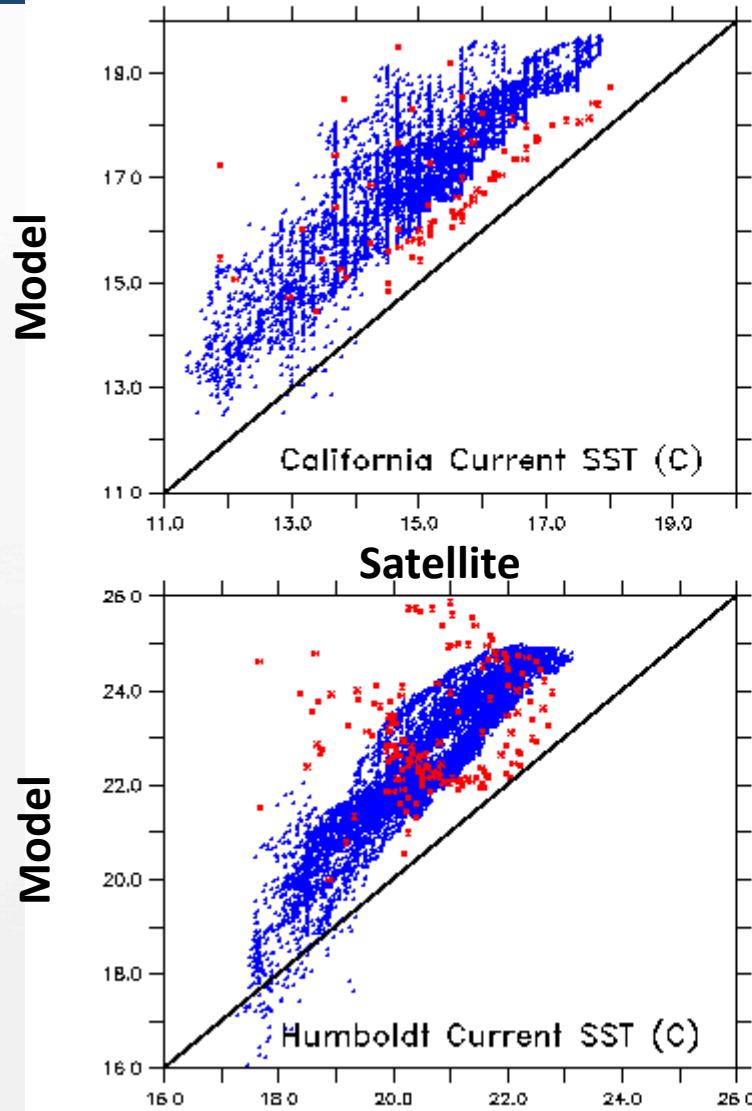
Observations/  
reanalysis  
(AVHRR; ECCO)



# Offshore SST in Obs, ESM2M, and ESM2.6

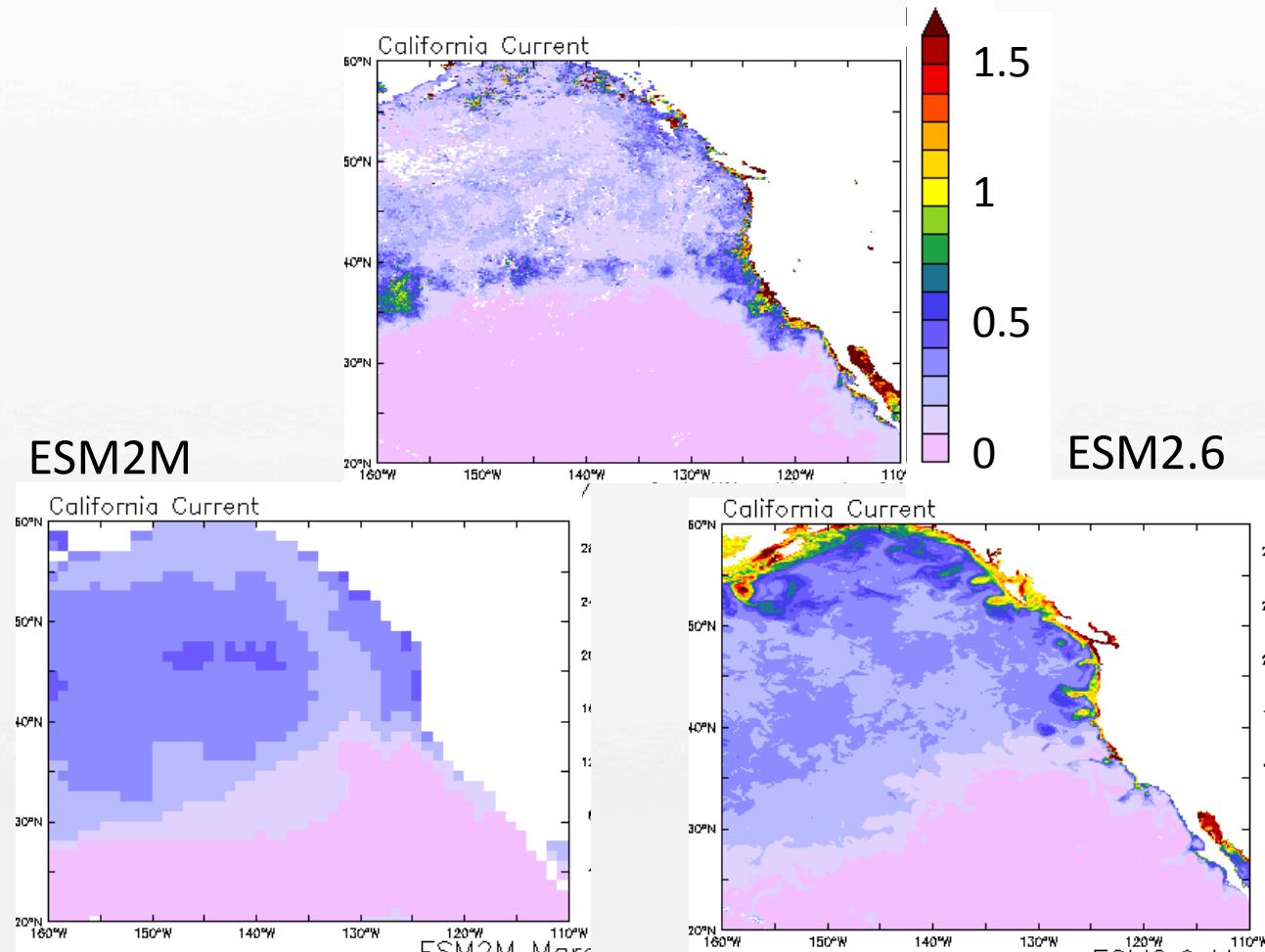


# Offshore SST in ESM2M/ESM2.6 vs. Obs.



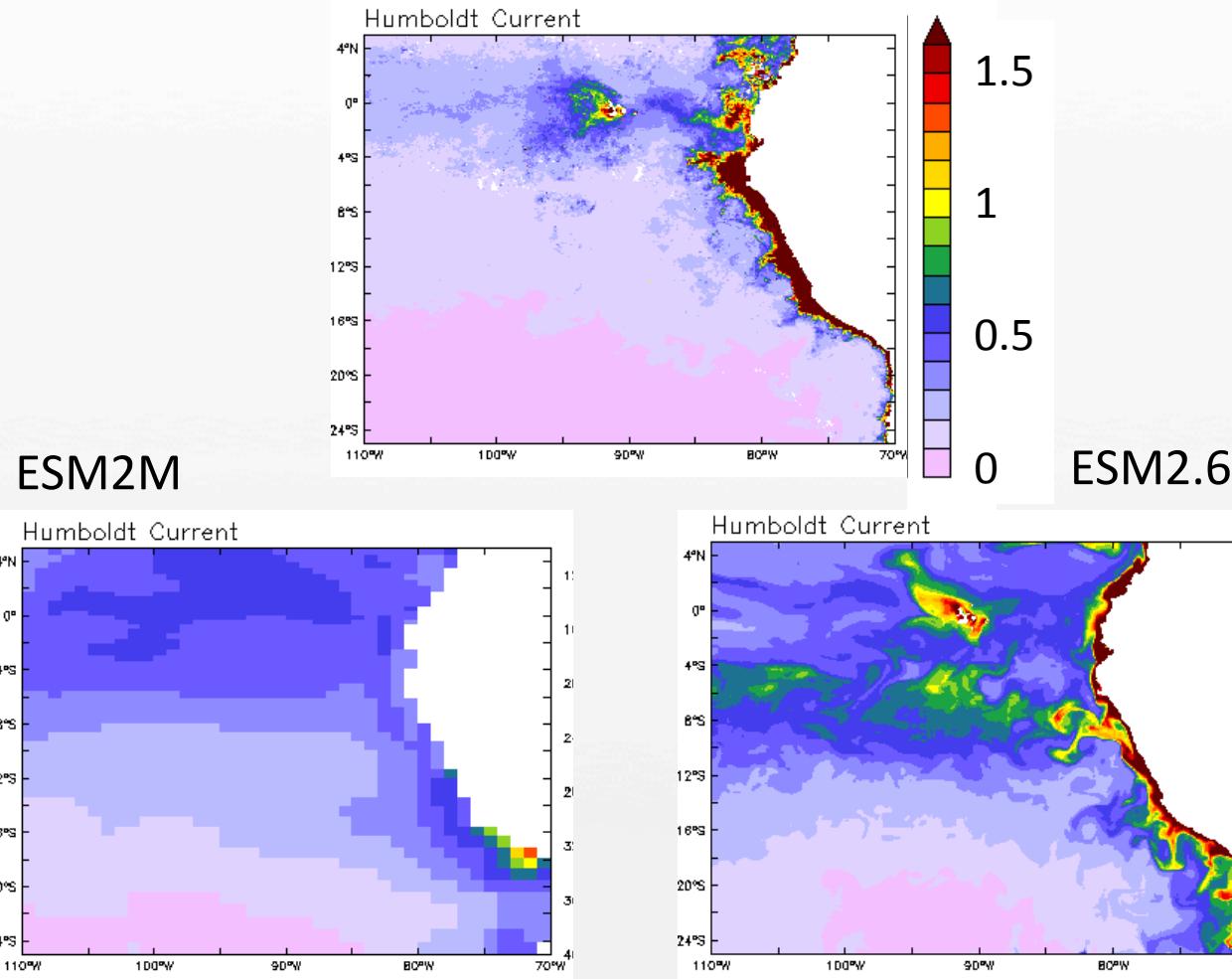
# California Current Surface Chlorophyll

Satellite-based surface Chlorophyll ( $\text{mg Chl m}^{-3}$ )



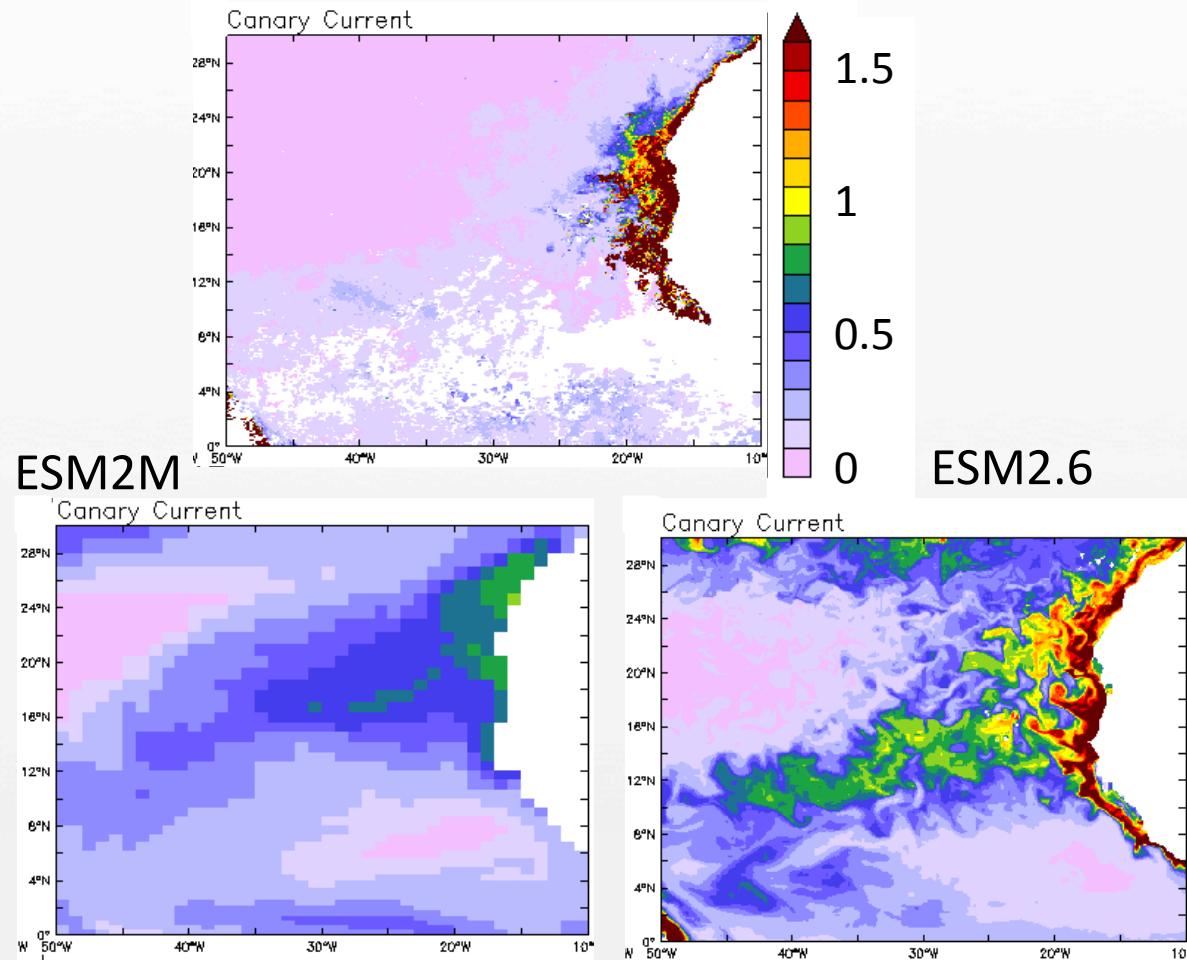
# Humboldt Current Surface Chlorophyll

Satellite-based surface Chlorophyll ( $\text{mg Chl m}^{-3}$ )



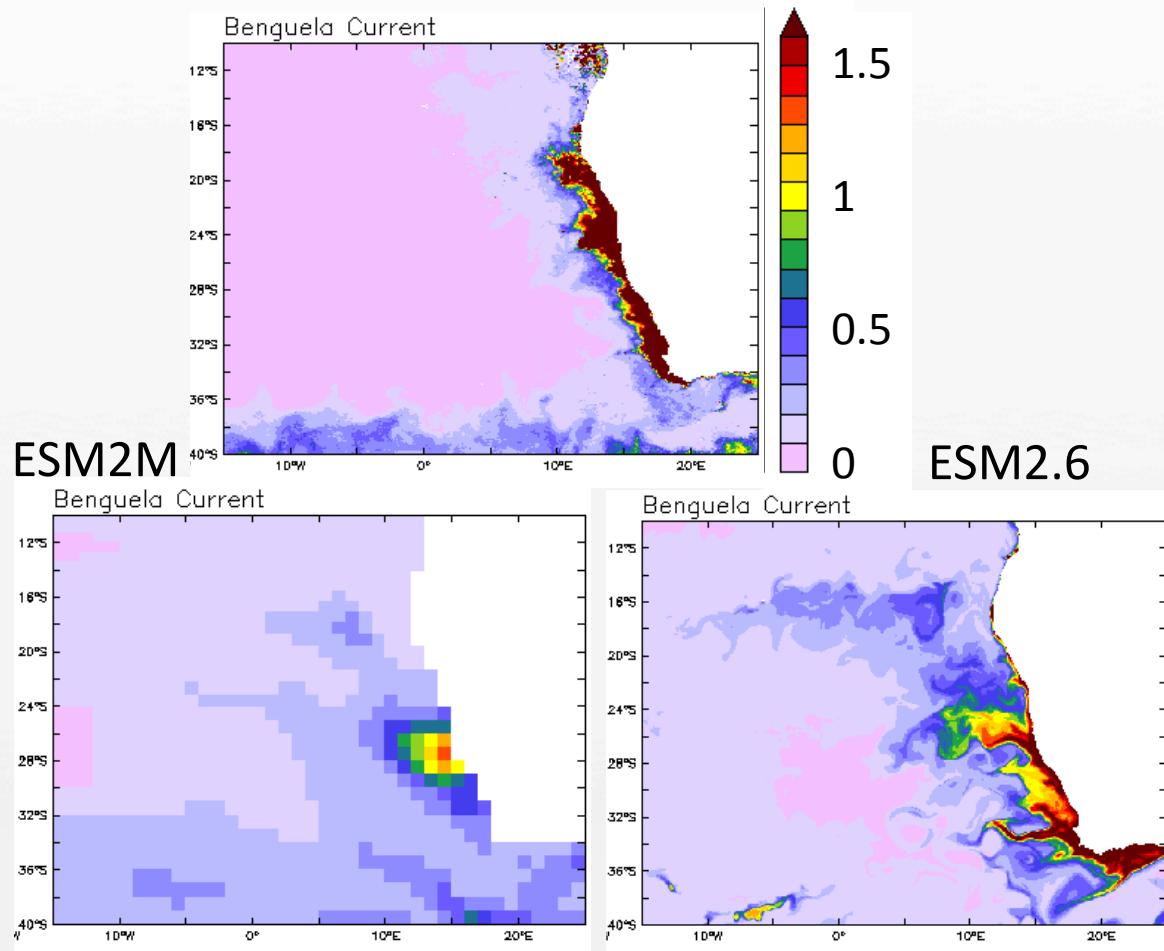
# Canary Current Surface Chlorophyll

Satellite-based surface Chlorophyll ( $\text{mg Chl m}^{-3}$ )

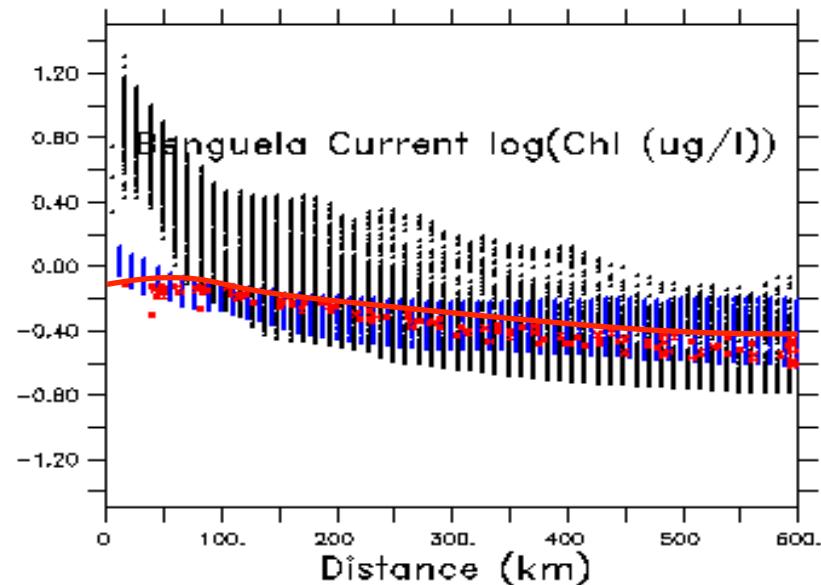
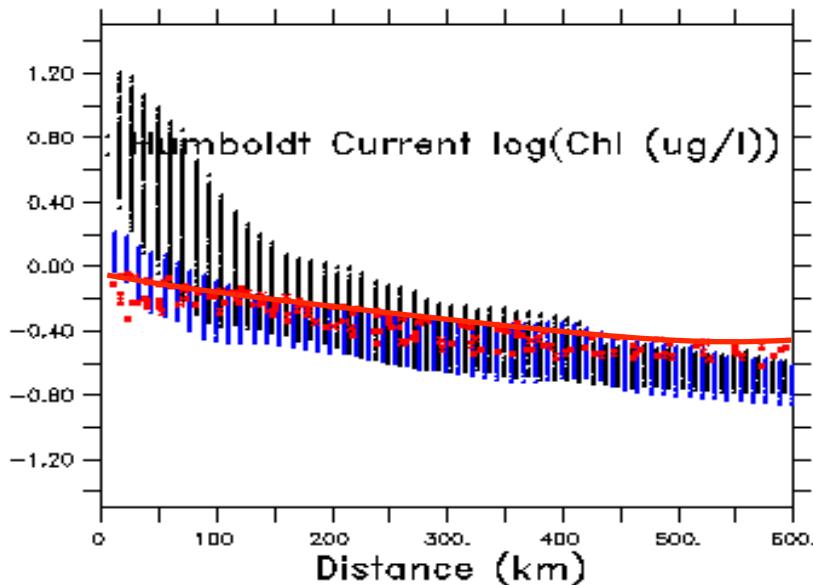
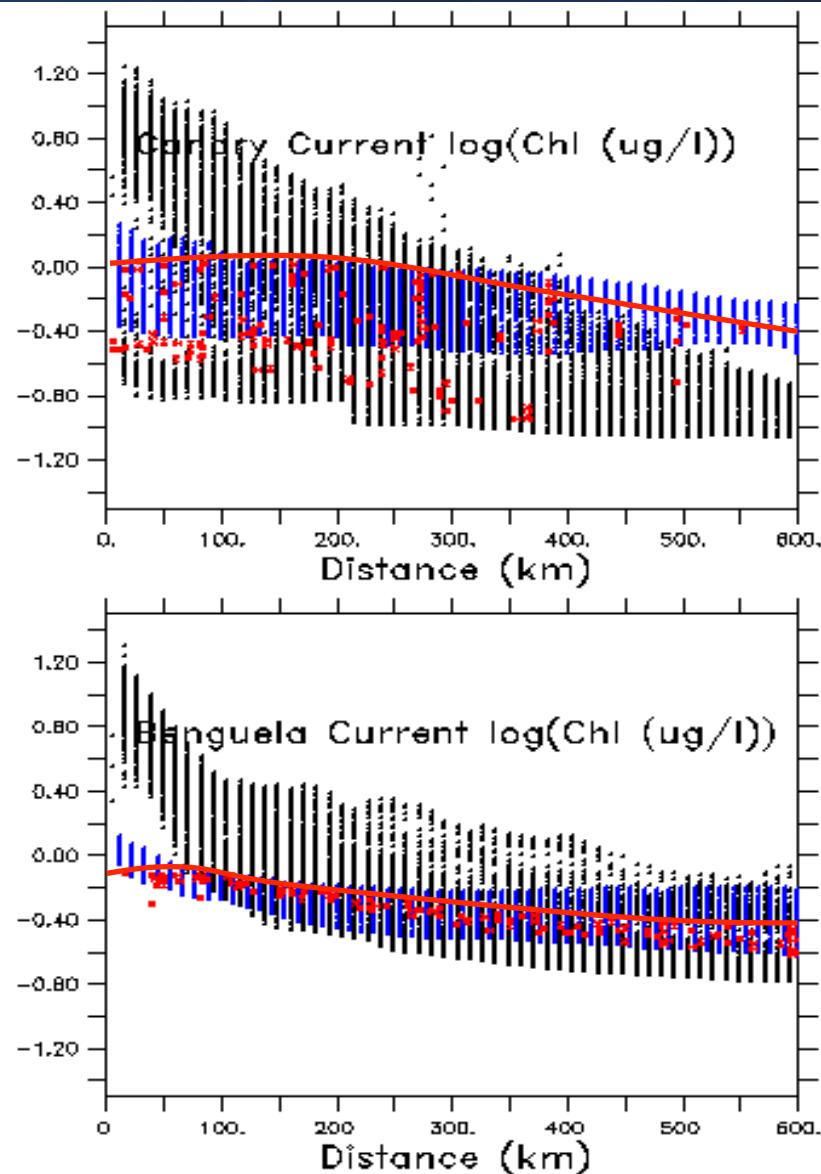
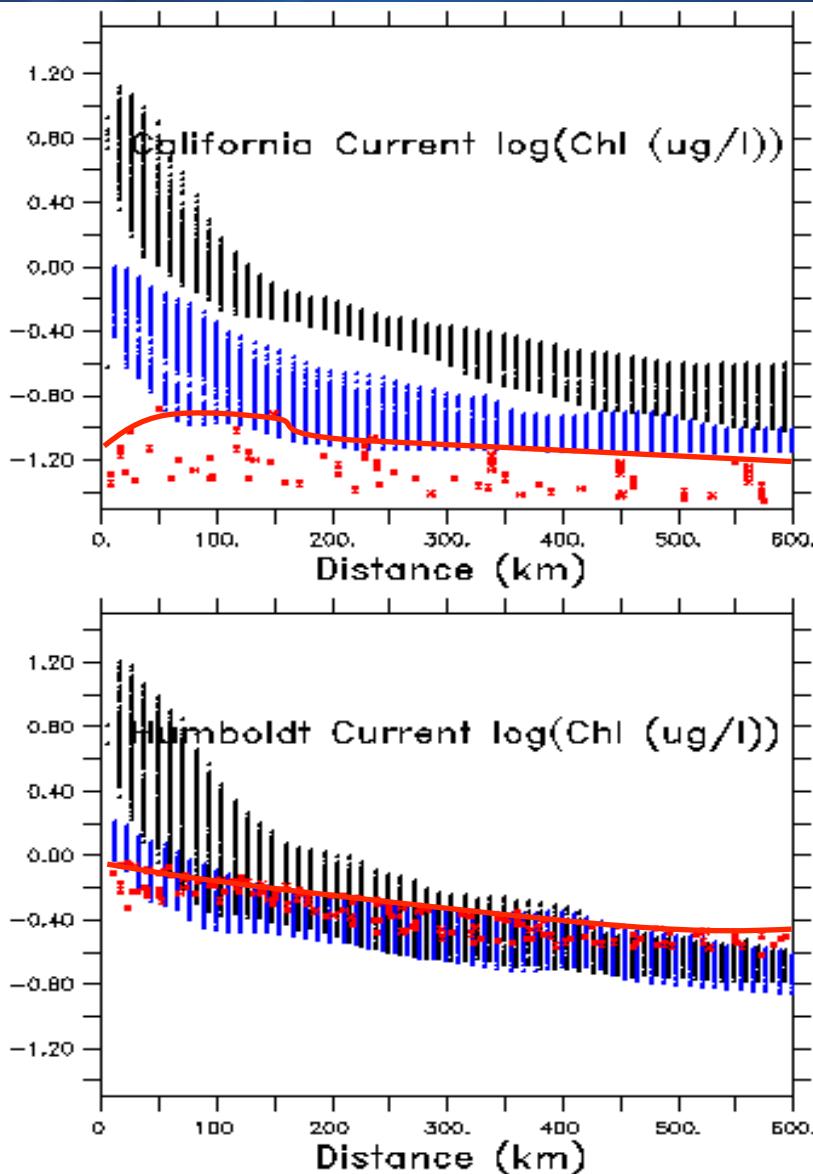


# Benguela Current Surface Chlorophyll

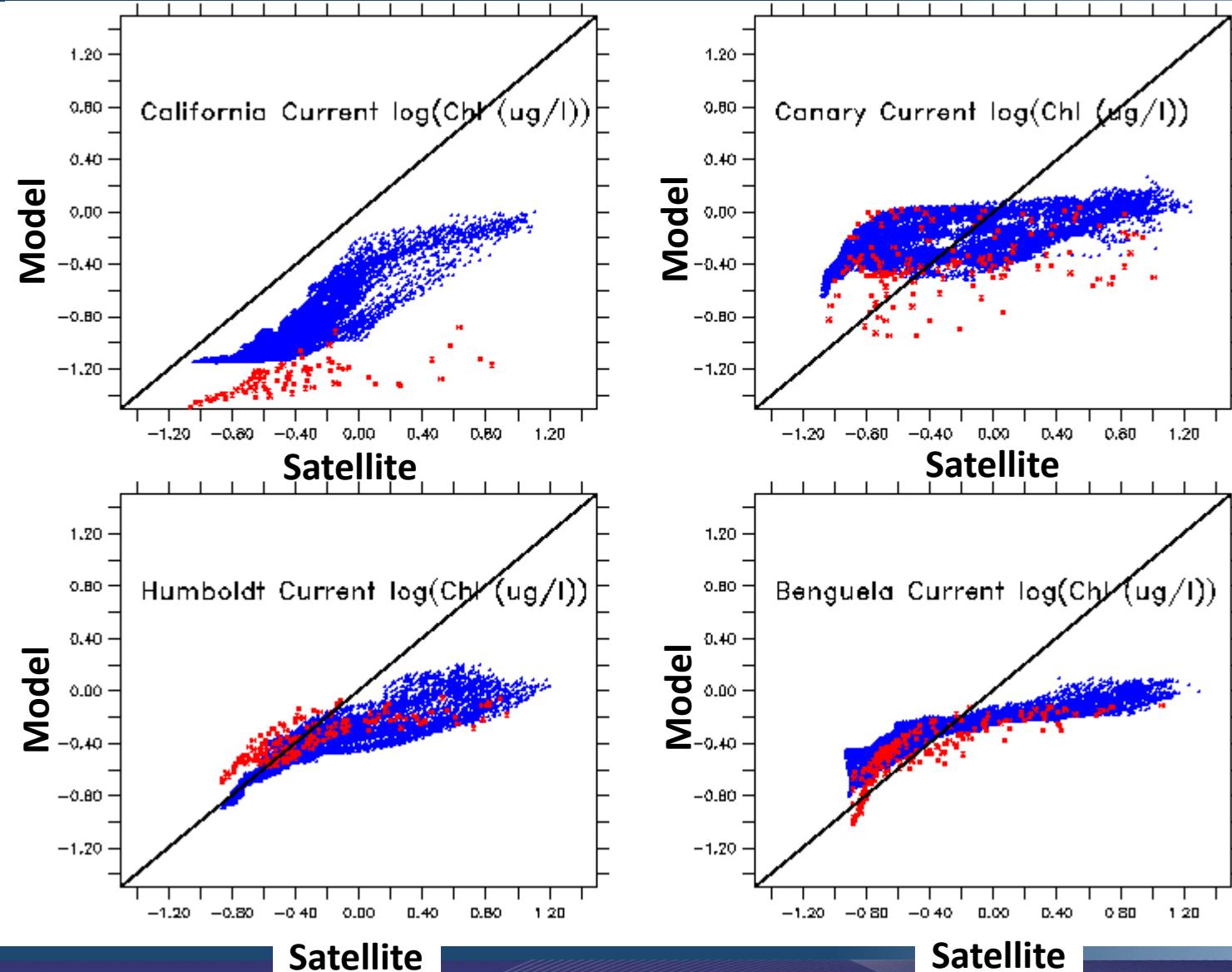
Satellite-based surface Chlorophyll (mg Chl m<sup>-3</sup>)



# Offshore Chl in Obs, ESM2M, and ESM2.6

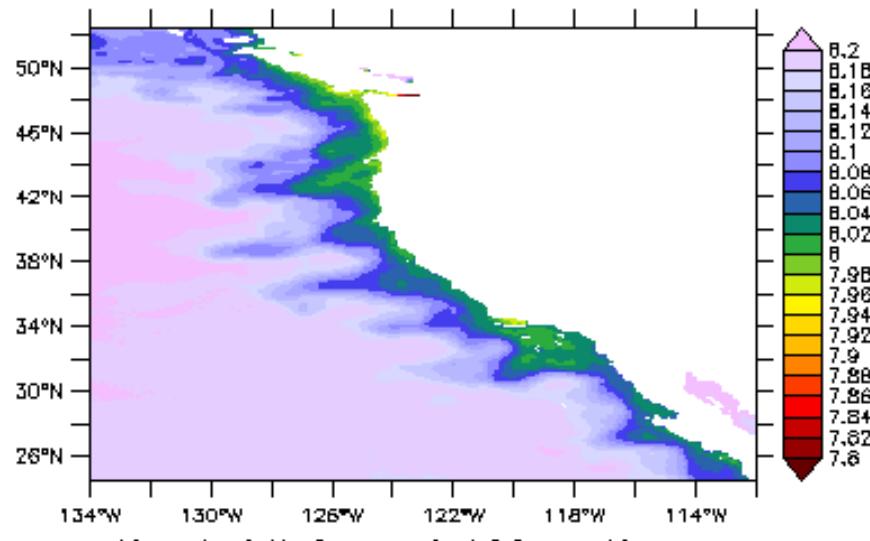


# Offshore Chl in ESM2M/ESM2.6 vs. Obs.

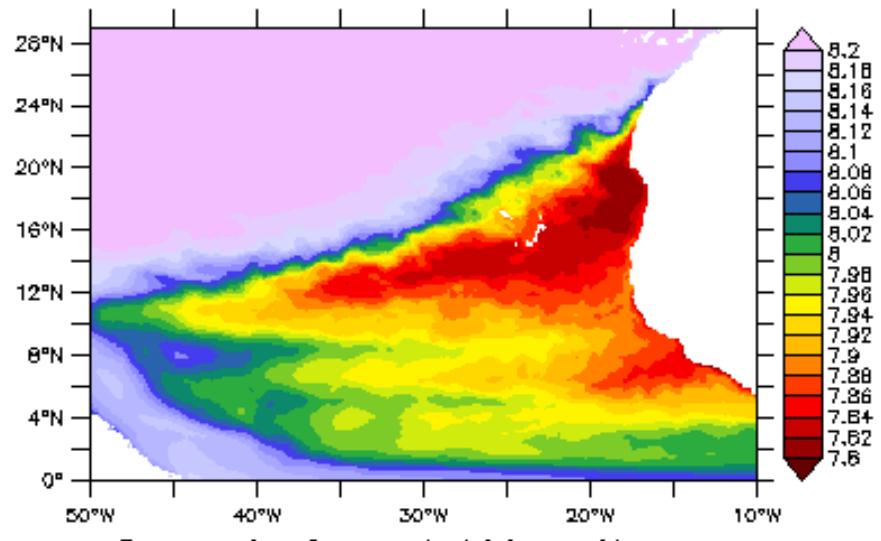


# ESM2.6 100 m pH

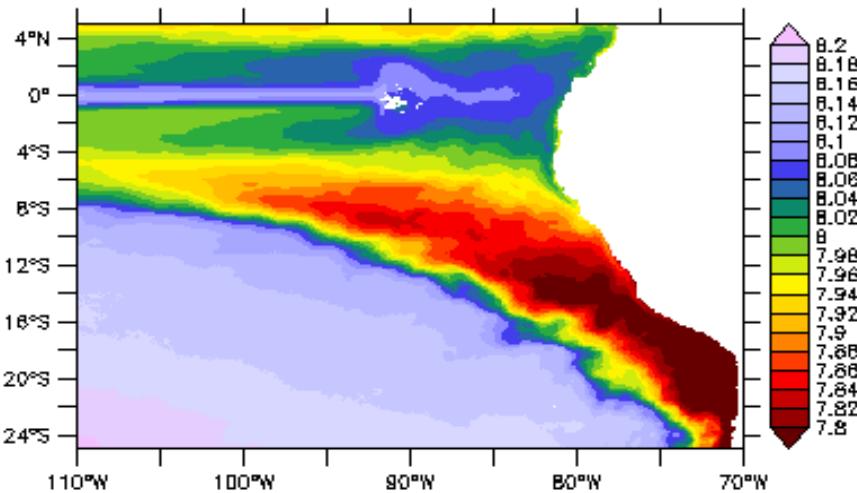
California Current 100m pH



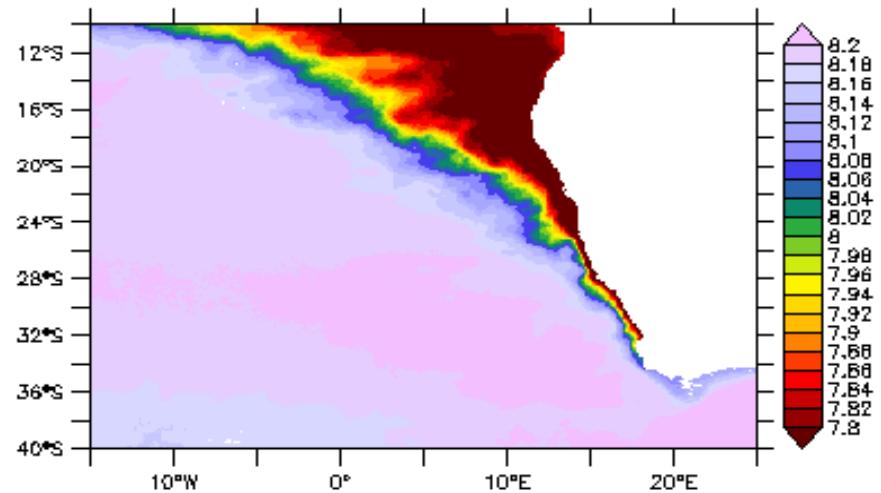
Canary Current 100m pH



Humboldt Current 100m pH

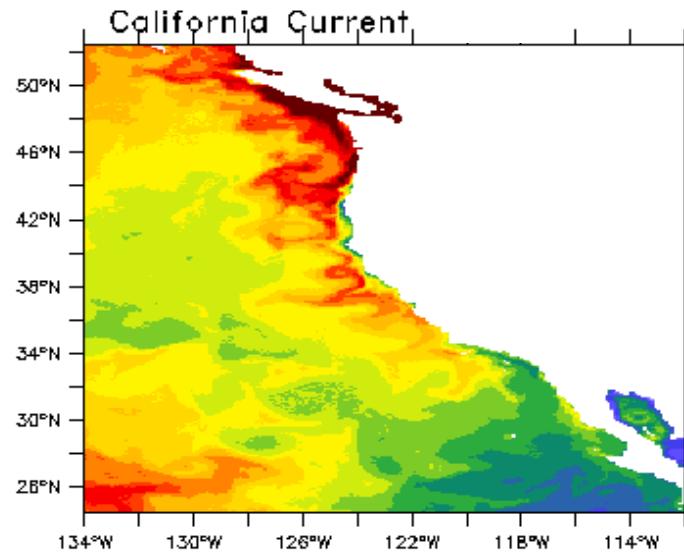


Benguela Current 100m pH

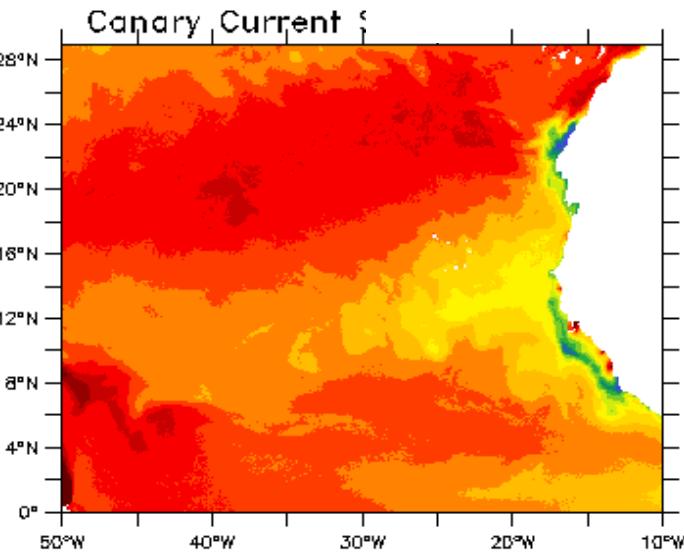


# ESM2.6 Surface pH

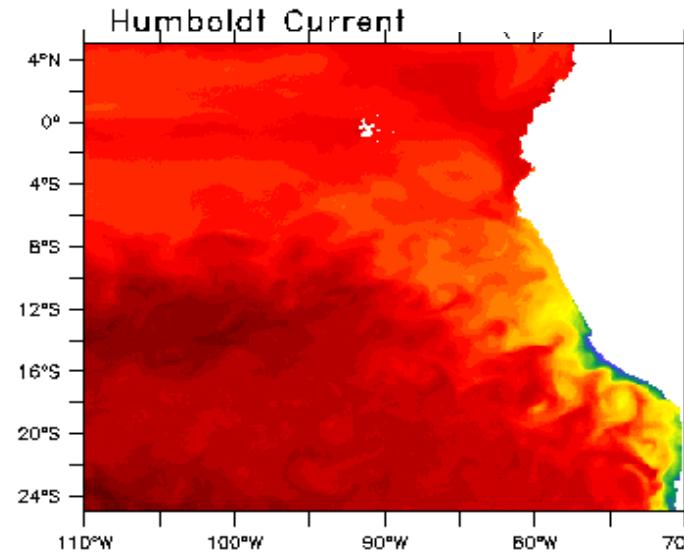
California Current



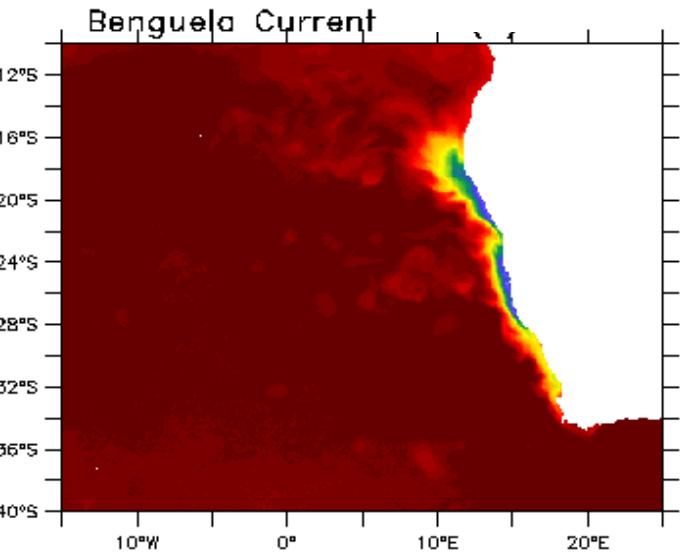
Canary Current



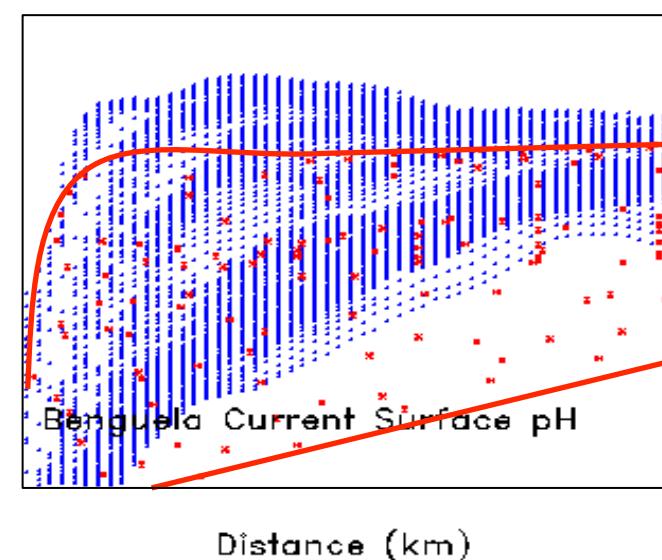
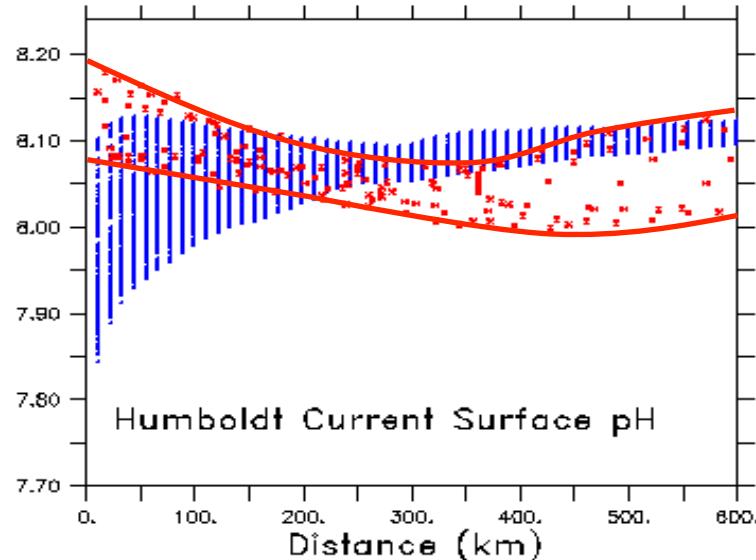
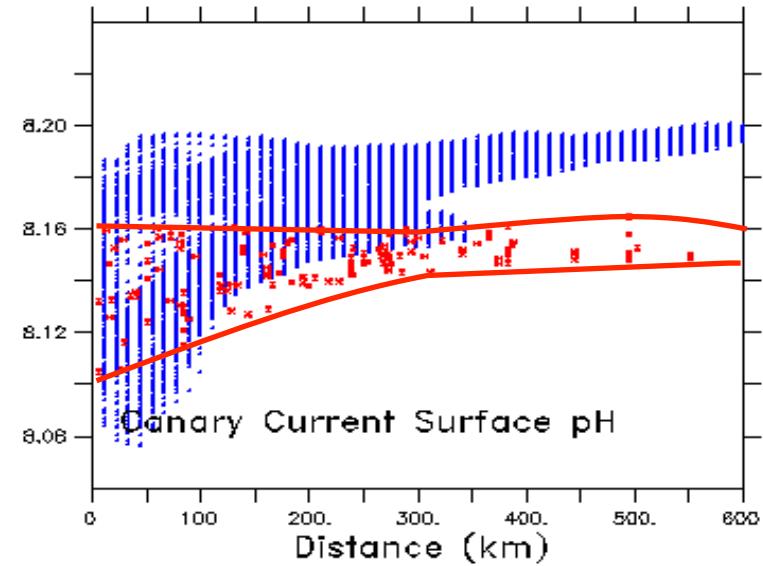
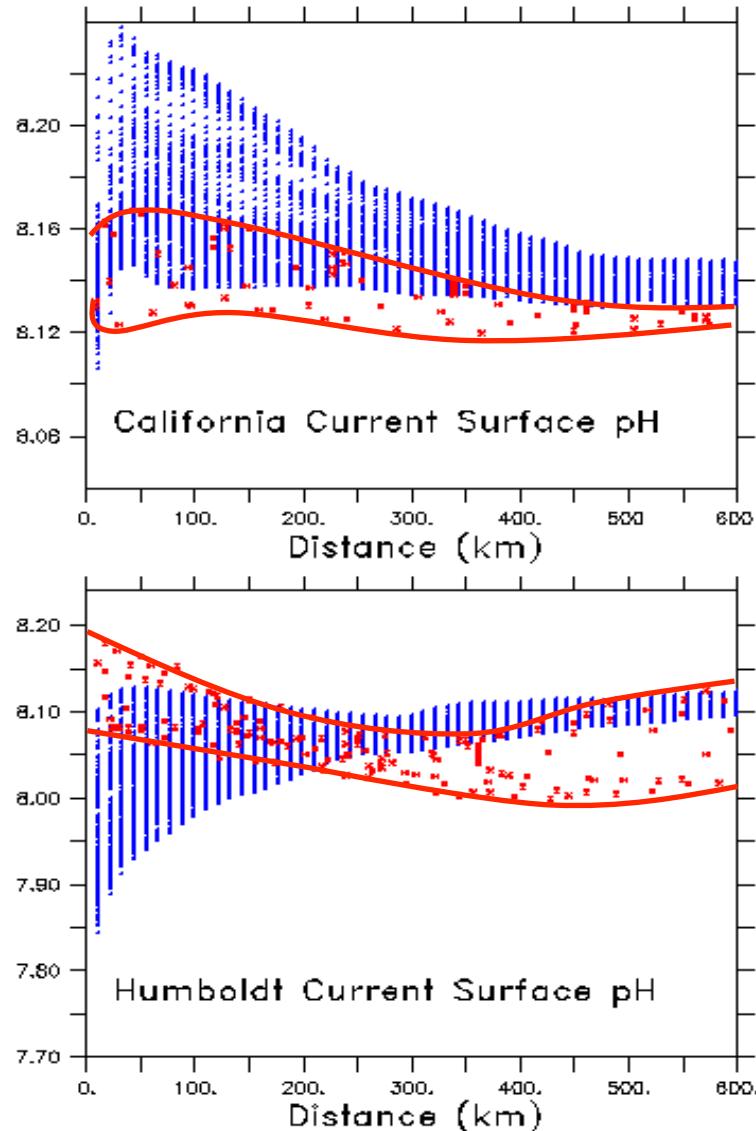
Humboldt Current



Benguela Current



# Offshore Surface pH in ESM2M and ESM2.6



# Progress and Challenges

Novel and synergistic approaches will be necessary for the science

- Many touchstone experiments are necessary for full exploration of uncertainties
- Critical to exercise multiple applications of the same model run

Initial prototyping demonstrates strengths at mesoscale representation:

- SST gradients are generally well-represented.
- Chlorophyll gradients exist, but are still damped.
- pH gradients exist and have complex structure awaiting further analysis

Many challenges remain:

- Many large scale biases still exist at high resolution and await further development
- Coastal acidification a work in progress
- Benthic-Pelagic, Estuarine and other interactions still missing
- Reduced BGC algorithm alternatives require careful inspection